

## Robust Telerobotics — An Integrated System for Waste Handling, Characterization and Sorting

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### Abstract

Mixed waste is a growing national problem. Annual generation of mixed waste is estimated to be 30,000 m<sup>3</sup>/yr, and an estimated 300,000 m<sup>3</sup> of low-level mixed waste is now in storage nationally. Few acceptable treatment and disposal methods for mixed waste are currently available, resulting in increased storage requirements at DOE and other mixed waste generators' facilities. It is expected that without development of credible solutions for the disposal of these wastes, authority to store mixed waste under the Federal Facilities Compliance Act of 1992 (FFCA) will be jeopardized.

The Mixed Waste Management Facility (MWMF) at the Lawrence Livermore National Laboratory (LLNL) was designed to serve as a national testbed to demonstrate integrated technologies for the treatment of low-level organic mixed waste at a pilot-plant scale. Pilot-scale demonstration of the technologies serves to bridge the gap between mature, bench-scale proven technologies and full-scale treatment facilities by providing the infrastructure needed to evaluate technologies in an integrated, front-end to back-end, facility. In this context, "integrated" means that the facility was designed to demonstrate state-of-the-art waste characterization and feed preparation technologies, the best mature treatment systems, and the preparation of robust ceramic final forms as a system rather than individually. The front-end consists of waste receipt, initial screening, characterization and sorting, and preparation. Consistent with the intent to focus on technologies that are ready for pilot scale deployment, the front-end handling and feed preparation of incoming waste material has been designed to demonstrate the application of emerging robotic and remotely operated handling systems.

Remote operations have traditionally been performed by several classes of master-slave manipulators including teleoperators, telemanipulators and telerobots. As one moves from teleoperators to telerobots, the ability to control the system in an autonomous manner increases. Telerobotics provides the flexibility needed to increase or decrease the amount of automation or operator intervention according to task complexity. It also provides an inherent backup in that it can be operated in a teleoperated mode as required. Telerobotics was chosen for deployment in MWMF over manual, teleoperated or fully automated designs for waste characterization and sorting. The choice was based on expected levels of risk associated with processing typical DOE mixed waste, the bench-scale maturity of the technology, and the potential to advance the technology to increase productivity of operations.

As part of the MWMF design effort in telerobotics, engineering development was performed first on a PUMA 560 system and then on a plant prototypic Schilling Titan III system. The primary goal of MWMF's engineering development work in telerobotics was to reduce the technical risk of deploying the technology in MWMF by answering key technical questions through focused developments and demonstrations. The work focused on integrating key tools to, 1) make a robust telerobotic system that operates at speeds and reliability levels acceptable to waste handling operators and, 2) to demonstrate an efficient operator interface that minimizes the amount of special training and skills needed by the operator.

This paper describes the design and operation of the prototype telerobotic waste handling and sorting system that was developed for MWMF. The work was performed at LLNL in collaboration with Schilling Robotic Systems and with the support of Oak Ridge National Laboratory. Key system elements that contribute to robust teleoperation include a truly seamless transfer between teleoperation and autonomous operations, a major advance in whole-arm-to-whole-workcell collision avoidance that is operational during all autonomous and teleoperational moves, force compliant arm behavior, and a real-time on-the-fly collision-free path-planner. The operator interface is keyboard-less and demonstrates key elements of the MWMF design including a force-reflecting hand controller that provides operator inputs in a novel hybrid position/rate mode, a speaker-independent natural language-based voice recognition system, and a reconfigurable graphics and video display system that can be tailored to the operator. The system has been in operation since June, 1996 and is expected to be complete and ready for testing with waste handling technicians in September, 1996.

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